NASA METEOROID ENVIRONMENT OFFICE

The 2024 meteor shower activity forecast for the lunar surface

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The purpose of this document is to provide a forecast of major meteor shower activity on the lunar surface. While the predictions in this document are for the surface, spacecraft orbiting the Moon at low altitudes will encounter meteoroids at similar rates. Most annual showers are expected to display typical activity, but the eta Aquariids (ETA) are once again expected to exhibit more than double their typical activity level. A complete discussion of expected meteor shower activity in 2024 is available in the meteor shower activity forecast for low Earth orbit [1].

1 Overview

This document is designed to supplement risk assessments that incorporate an annual averaged meteor shower flux (as is the case with all NASA meteoroid models). Results are presented relative to this baseline and are weighted to a constant kinetic energy. Note that meteor shower fluxes drop dramatically with increasing particle energy. Thus, a PNP (probability of no penetration) risk assessment should use the flux and flux enhancement factors corresponding to the smallest particle capable of penetrating a component because the flux at this size will be the dominant contributor to the risk.

The fluxes given in this forecast are those on the lunar surface at each shower's subradiant point. An individual spacecraft or single, fixed location on the lunar surface – such as the lunar south pole – will experience significantly reduced fluxes from showers whose radiants lie far off the surface normal vector. Some showers will be blocked entirely. Please contact the Meteoroid Environment Office (MEO) if a location- or trajectory-specific forecast is needed.

2 Details

Figure 1 gives the flux profiles for four limiting kinetic energy values, listed in Table 1. The equivalent mass, at a speed of 20 km s^{-1}, and diameter, for a density of 1 g cm^{-3}, are provided in Table 1. Showers typically contain proportionally more large particles than the sporadic background does; for this reason, showers are more significant at larger particle sizes, masses, or energies. Figure 1 also includes an estimate of the sporadic meteoroid flux for each of these limiting kinetic energies (horizontal lines). Note that for small particle sizes (low kinetic energies), shower fluxes are less significant compared to the sporadic flux. The directionality, speed, and timing of all forecasted showers relative to the Moon are listed in Table 2. For a spacecraft, the apparent directionality of a meteor shower (i.e., the aberrated radiant) will be shifted by the spacecraft's selenocentric velocity.

The fluxes in Figure 1 reflect the Moon's smaller gravitational pull. As meteoroids approach a massive body, they are accelerated and concentrated by the body's gravity [2, 3]. This effect is stronger for slow meteoroids, and, on average, sporadic meteoroids are slower than shower meteoroids. Near the Earth, where

the gravitational pull is large, shower meteoroids will constitute a smaller fraction of the environment than near the Moon. This is apparent if one compares Figure 1 with that of the LEO forecast [1]; here, the KE-limited sporadic flux has a lower value than in low Earth orbit, one that showers can more readily exceed (see, for instance, the Geminid peak in mid-December). Our forecasting algorithm is described in more detail in [4].

In order to facilitate risk assessments, including Bumper PNP (probability of no penetration) calculations, we provide flux enhancement factors for all of 2024 in 1-hour intervals (Figure 2). These factors represent the increase in the meteoroid flux due to showers over the baseline sporadic flux. The larger flux enhancement factors in Figure 2 correspond to a kinetic energy of 105 J (0.1-cm-equivalent particles), which have lower absolute fluxes. The fluxes and enhancement factors presented in this memo may or may not apply to individual spacecraft. For instance, we have not presented crater-limited fluxes; meteoroids incident on a surface at right angles penetrate deeper for many ballistic limit equations, and, for a surface directly facing the shower, this can further boost the significance of a shower relative to the background by another factor of approximately 2 [4]. Conversely, a surface tilted away from the shower radiant will encounter a less significant flux enhancement, and it is possible for the Moon to shield a spacecraft from all or part of a shower at a particular point in time.

3 Contact information

Those with questions or special needs are encouraged to contact:

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kinetic energy	**equivalent mass** at 20 km s^{-1}	**equivalent diameter** at 1 g cm^{-3}
6.7 J	3.35×10^{-5} g	0.04 cm
105 J	5.24×10^{-4} g	0.1 cm
2.83 kJ	1.41×10^{-2} g	0.3 cm
105 kJ	5.24×10^{-1} g	1.0 cm

Table 1: The limiting kinetic energies (and their equivalent masses and diameters at 20 km $\mathbf{s^{-1}}$ and 1 g $\mathbf{cm^{-3}}$) to which we report fluxes and enhancement factors.

References

[1] Moorhead, Moser, and Cooke. The 2024 meteor shower activity forecast for low Earth orbit. Issued by the NASA Meteoroid Environment Office on 2 November 2023.

[2] Staubach, Grün, and Jehn. The meteoroid environment near earth. *Advances in Space Research*, 19(2):301–308, May 1997.

[3] Jones and Poole. Gravitational focusing and shielding of meteoroid streams. *Monthly Notices of the Royal Astronomical Society*, 375(3):925–930, Mar 2007.

[4] Moorhead, Egal, Brown, Moser, and Cooke. Meteor shower forecasting in near-Earth space. *Journal of Spacecraft and Rockets*, 56(5):1531–1545, 2019.

[5] Moorhead, Kingery, and Ehlert. NASA's Meteoroid Engineering Model (MEM) 3 and its ability to replicate spacecraft impact rates. *Journal of Spacecraft and Rockets*, 57:160–176, 2020.

shower name	radiant		speed	date of maximum
	RA (°)	dec (°)	(km s^{-1})	(UT)
Quadrantids	231.5	48.0	40	2024-01-04 02:51
eta Aquariids	339.1	-0.4	65	2024-05-05 10:59
Daytime zeta Perseids	68.0	23.6	28	2024-06-02 15:02
Daytime Arietids	42.8	24.1	37	2024-06-09 23:40
Southern mu Sagittariids	274.5	-29.5	28	2024-06-19 18:40
Southern delta Aquariids	343.3	-15.6	40	2024-07-27 17:34
alpha Capricornids	305.6	-8.7	22	2024-07-30 21:09
Perseids	45.8	57.9	59	2024-08-12 18:10
Daytime Sextantids	156.2	-1.9	31	2024-10-01 20:58
October Draconids	265.0	52.8	20	2024-10-08 15:14
Orionids	96.0	15.7	66	2024-10-21 22:19
Southern Taurids	47.9	12.6	25	2024-11-05 06:12
Northern Taurids	61.1	23.8	28	2024-11-12 09:18
Geminids	112.4	32.2	34	2024-12-14 05:24
Ursids	213.3	74.4	31	2024-12-22 00:44

Table 2: Radiant, speed, and time of peak activity at the Moon for all forecasted showers in 2024. Radiants are selenocentric and correspond to the time of peak activity. The speed is taken at the lunar surface. We report radiants to the nearest tenth of a degree in order to illustrate the difference between geocentric and selenocentric radiants; the precision remains approximately 1 degree.

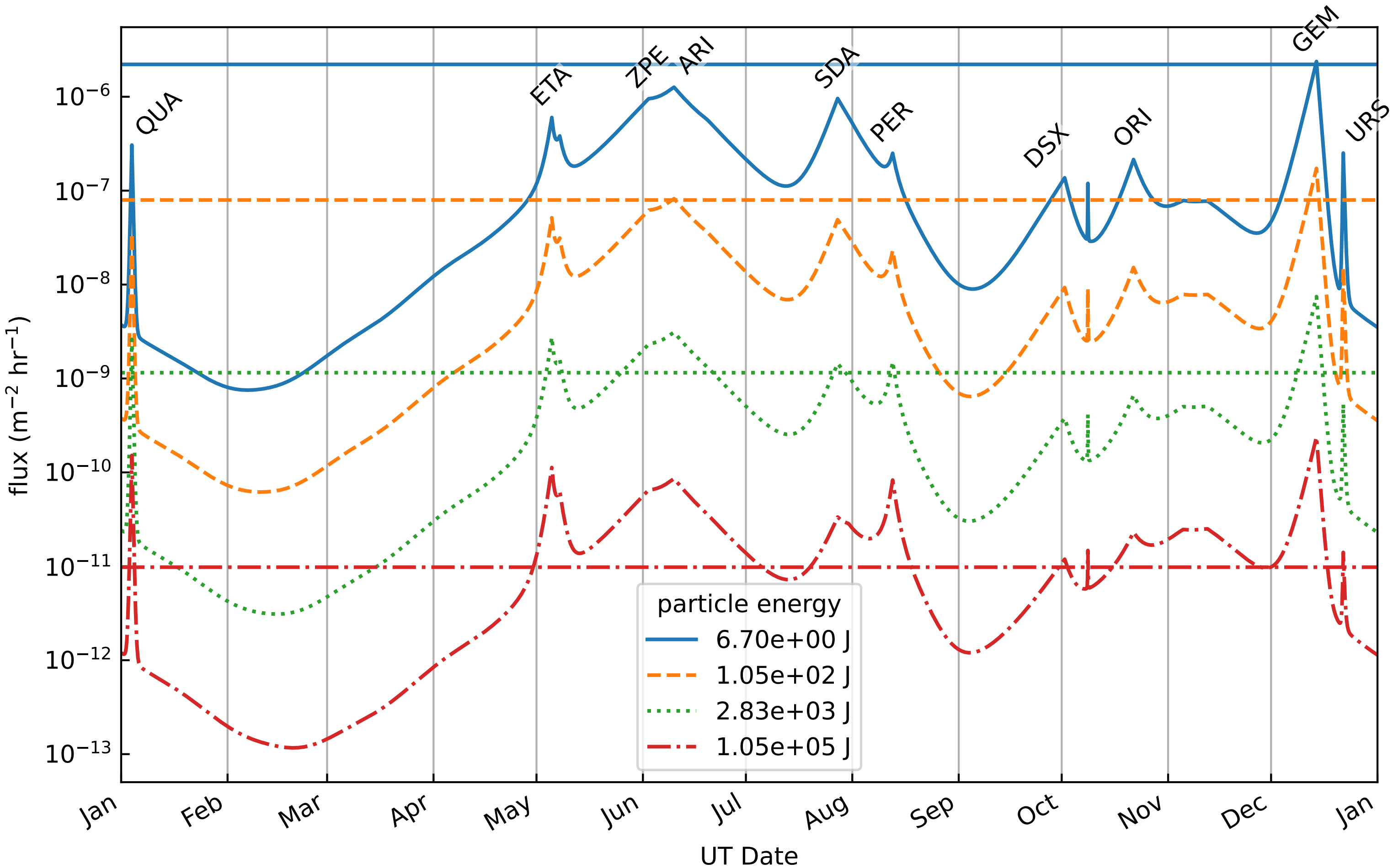

Figure 1: Meteor shower flux (variable lines) and sporadic meteoroid flux (horizontal lines) over the course of 2024. Fluxes are quoted to four limiting particle kinetic energies; these kinetic energies correspond to particles with diameters of 0.04 cm, 0.1 cm, 0.3 cm, and 1 cm, assuming a density of 1 g cm^{-3} and a speed of 20 km s^{-1}. Some showers, such as the Perseids (PER) and Quadrantids (QUA), are more heavily weighted toward large particles and thus play a more significant role for 1-cm-equivalent particles (red curve) than for 0.04-cm-equivalent particles (blue curve).

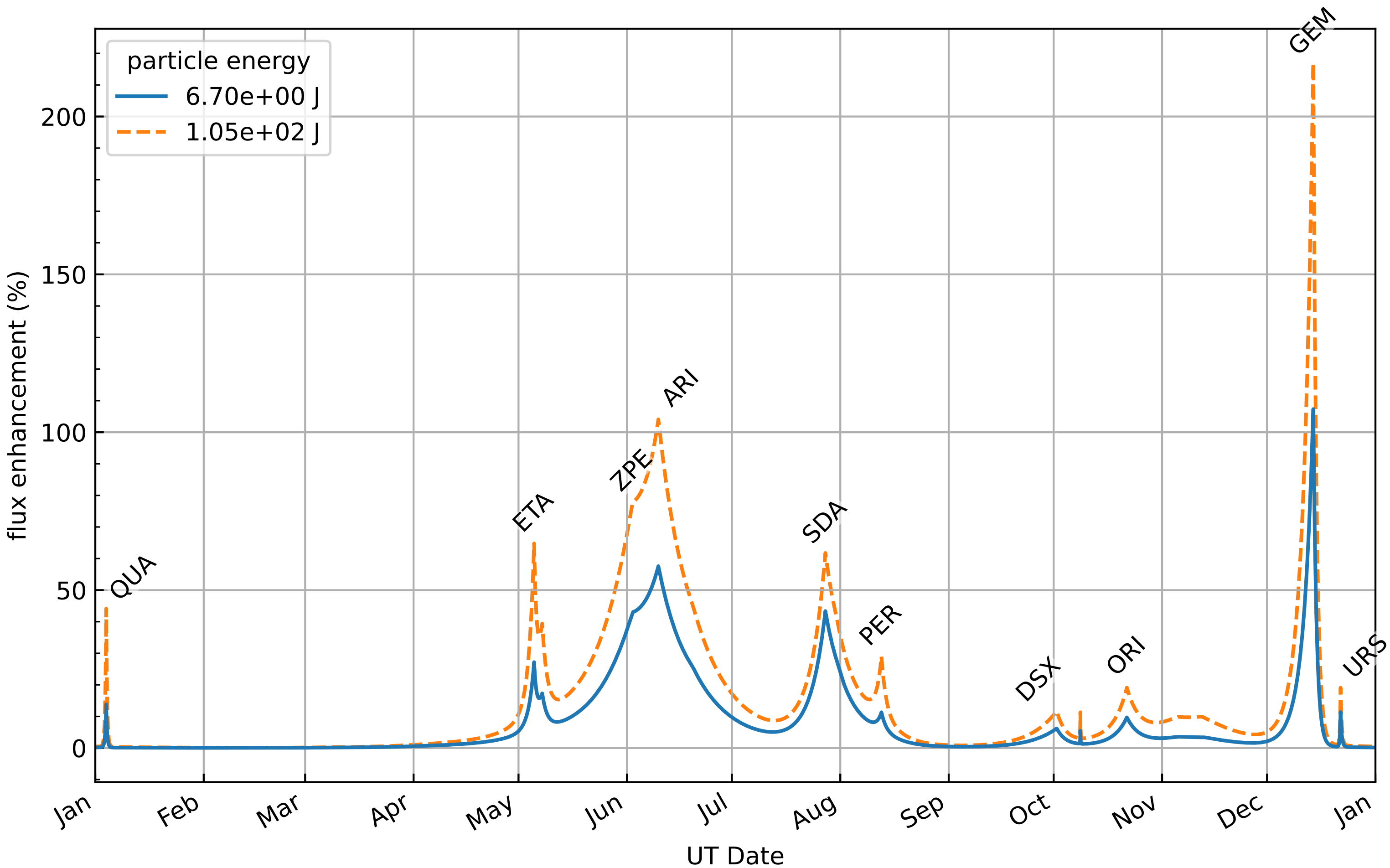

Figure 2: Meteor shower flux enhancement relative to the sporadic meteoroid flux over the course of 2024. These factors can be used in conjunction with a meteoroid model such as the Meteoroid Engineering Model (MEM) [5] to compute the flux at a particular point in the year on a plate facing the unobscured shower radiant.